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PLASTOGRAPH EVALUATION OF THE EFFECT OF BENTONITES ON BRICKMAKING SHALES FROM CANADA BRICK COMPANY, LIMITED

by

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ABSTRACT

The Brabender Plastograph was used to examine the effect of several commercially available bentonites on the plasticity of the Queenston shales used for brick manufacture by Canada Brick at the company's Burlington and Streetsville plants. The work was performed under Cost Recovery Job 025145.

All of the bentonites raised the plastogram peak height, indicating improved plasticity, i.e., the material with additives could be deformed to a greater degree without rupture. In addition, the sodium bentonites, owing to their thixotropic nature, tended to countermand the inherent dilatent tendencies of the shales, which are sometimes manifest in difficultextrusion and poor mechanical appearance of the bricks. Although more readily dispersed, calcium bentonite was less effective in improving plasticity and had little if any beneficial effect vs. dilatency.

Bentonite additions tend to promote earlier development of optimum plasticity and thus to reduce the required pugging time.

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INTRODUCTION

At the request of Canada Brick Company Limited, Streetsville, Ontario, (J.P. Storer-Folt, Manager of Technical Services) studies were conducted using the Brabender Plastograph to evaluate the effect of additions of various commercially available bentonites on the plasticity of the company's brickmaking shales from Burlington and Streetsville, Ontario. The work was performed under Project 3.0.2.9.99, "Cost Recovery in Mineral Processing", Job No. 025145.

PLASTOGRAPHY

Methodologies featuring the use of the Barbender Plastograph were established in the Ceramic Section, Mineral Sciences Laboratories, CANMET, in the early 1960's (1). Since then the instrument has been much used to evaluate plasticity and predict extrusion behaviour of many Canadian clays, shales and other materials with significant success.

The Plastograph as used for clays and shales is essentially a double-shafted pugmill, with the shafts driven differentially by a constant-speed motor through a dynamometer, with means to both indicate and record the torque, in metre.grams, required to overcome the resistance to the shearing action of the blades through the clay paste in the mixer. The procedure used in the Ceramic Section, based on multiple trials and experience, is to fill the mixer with dry material (normally 200 g) to a level that, when wet, will be halfway up the shafts, which provides most efficient mixing. Water is then added at a controlled rate of 1.0 wt % of dry clay per min. These dynamic conditions produce a rising curve of increasing resistance to shear with increasing plastic strength, which eventually peaks and then falls off as the material becomes soft and more easily sheared. Faster rates of water addition produce lower and sharper peaks. Slower rates show little change and are more time-consuming: the minor increases occasionally due to slower rates are attributed to additional plastic fines produced by abrasion of densely aggregated clay or shale particles. Hence, this procedure is considered to develop the optimum plasticity inherent in the material under test.

Experience indicates that extrusion of mechanically sound bricks requires a minimum peak height of 600 to 650 m.g although, given a sufficiently powerful extruder, materials with this inherent level of

plasticity can be successfully extruded with less than the indicated water content. Presumably, under the great pressures developed, a thinner layer of water serves to lubricate the particles. Similarly, thin-wall tile require an indicated minimum peak height of about 900 m.g to eliminate dog-eared corners and torn internal webs. For stiff extrusion as normally practiced in Canada, the breadth of the peak is rarely significant as water content is usually well below the peak maximum, but for European-type soft extrusion, or for bodies for jiggering or roll-forming, a wide flat-topped peak allows for considerable change in moisture content without significant change in formability or green strength. Some materials show narrow, sharply rising early peaks apparently superimposed on the normal peak: this is attributed to high content of pseudo-plastic silt. As these fine non-plastic materials are usually dilatent (shear-thickening) their presence results in increased power consumption and, in the worst case, "freezing" of the material under the shearing action of the augers. Where extrusion is possible, owing to compensating amounts of thixotropic clay minerals, such materials invariably show laminar flow, with all the attendant problems of structural weakness and poor frost resistance. By way of example, some typical plastograms are shown in Fig. 1. Curve (1) is for a poorly plastic shale: with a peak of just under 500 m.g it is impossible to consistently extrude a column of sound mechanical appearance. It also tends to dilatency: under pressure in the auger chamber, water is expressed from the wet body, in the same way as the pressure of one's weight leaves dry footprints behind when one walks on a wet sand beach. This stiff dry shale builds up behind the die over the auger front until it effectively stops flow. This characteristic is however only evident on the plastogram as a secondary peak when the shale is ground substantially finer than for brickmaking, indicated by the broken curve. This shale can be successfully extruded with the addition of a plasticizer such as plastic clay or bentonite. Curve (2) is for a shale of different character, with a well-rounded peak of just over 900 m.g. This material can be used to make excellent brick and also for tile with a minimum of dog-earing or web tearing. Curve (3) is a common clay of highly silty character, an exceedingly plastic material showing a high-rising sharp peak superimposed on the normal one. The material laminates badly. With a large addition of fine sand from an underlying stratum to inhibit lamination, the clay has been used to manufacture farm drain tile and like

products. Curve (4) is a non-clay (non-plastic) material; fine-grained iron oxide from the dust collector of a Canadian blast furnace. Its pseudo-plasticity is evident from the normal rising curve of the plastogram. However, its dilatent nature caused the material to literally "freeze" in the mixer, driving the torque beyond the capacity of the instrument and rupturing the protective shear-pin.

PROCEDURE AND RESULTS

PREVIOUS STUDIES

Some earlier studies, performed for Avonlea Mineral Limited, had shown the beneficial effects of additions of 3 sodium bentonite products, DG, SG, and SSG, in conjunction with Canada Brick's shales from Burlington and Streetsville. Some typical results are shown in Fig. 2 (2). When evaluating additives in this Laboratory, it is customary to add them in solution or slurry form to ensure maximum dispersion throughout the material under test. As almost all clays and shales show little effect with water additions of 10 wt % or less, the additives are added with the first 10% of water, in bulk, and allowed to mix thoroughly for several minutes before commencing the regular addition of water at controlled rate. With bentonite however, additions of more than 1 to 1.5 wt % can form highly gelled structures in 10 wt % of water, which do not appear to mix well. As a result, bentonite additions of 2% or more are added dry and thoroughly mixed before commencing the test. In Fig. 2, each of the lower curves represent the shales with no additions: the Burlington shale peaks at 800 m.g, the Streetsville shale at 1130 m.g. Thus, both samples have inherent plastic capabilities for satisfactory extrusion of brick; and the Streetsville material also for tile. In practice, both are stiff extruded for direct setting on kilncars with 13.5 to 14% water, which corresponds to about 500 m.g on the plastograms.

Both show a broad basic curve upon which is superimposed an early, small and rounded peak, attributed to dilatent non-plastic constituents and/or fine particles of shale that are effectively non-plastic owing to their relatively larger size than discrete clay minerals. These bentonite additions tend to negate this effect, their thixotropic behaviour counteracting the dilatent tendencies of the shale, as well as raising the

peak height (increasing plasticity). As the 3 bentonites are derived from essentially the same source, it was not surprising that there was little difference in their effect. Materials DG and SG were somewhat more effective, particularly at the lower levels of addition. The apparent anomaly in the curves for the Streetsville shale (the curve for 1% is disproportionately low) remains unexplained, although verified by repeat tests. The SSG bentonite showed similar results but a lesser degree of improvement, particularly at the lower levels of addition.

CURRENT WORK

The same shale samples were used for the present investigations, except where otherwise noted. An attempt was made to duplicate actual plant conditions as closely as possible. Thus, the usual plant additives were added along with the bentonite:

Streetsville shale; 0.04% Lignosol, 0.0625% $BaCO_3$,
Burlington shale; 0.04% Lignosol, 0.125% $BaCO_3$.

With all bentonite additions of 2.0% and more, all additives were added dry to the Plastograph mixer and thoroughly mixed with 10% water addition before commencing the regular addition of water at controlled rate. Bentonite additions of less than 2.0%, along with the normal additives, were pre-digested in 10% water addition in a beaker stirred with a propellor type mixer adjusted to maintain only a minimal vortex to avoid entrapment of air. Stirring was continued for 4 h immediately prior to the Plastograph run, which is considered the minimum turn-around time for mixing in plant conditions. (Although difficulties in dispersing Avonlea bentonites within this time frame had been reported by Canada Brick, all of the bentonites used in this investigation were judged to be fully dispersed in 4 h or less. Thus, although the effect of aging of the slurries may be of interest, no studies were conducted in this area.)

The first bentonite examined was "Dixie Bond"; a calcium bentonite from the southern U.S.A., which has been used at another of the company's plants in Laprairie, P.Q. The plastograms are shown in Fig. 3(a) for the Burlington shale. Additions of calcium bentonite serve to significantly raise the consistency (plasticity), although to a lesser degree than the Saskatchewan bentonites, particularly at the higher levels of addition,

e.g., 4% Dixie Bond gives a peak of 1160 m.g vs 1310 for 4% Avonlea DG. In addition the low-gelling, low thixotropy of the calcium bentonite does little if any to counter the dilatency of the raw shale: the superimposed peak remains essentially the same height. This behaviour was confirmed for additions to the Streetsville shale, Fig. 3(b). Here the calcium bentonite additions raise the peak height by about the same amount as do the Saskatchewan bentonites, but it effectively sharpens and extends the peak attributed to dilatency. Thus, although the mixture with Dixie Bond should be capable of being successfully deformed to complex shapes, such as thin webbed multicored brick or tile, experience indicates that laminar flow may be aproblem.

Further investigations of shale/bentonite mixtures involved 3 bentonite products: Dixie Bond calcium bentonite again; Volclay, a sodium bentonite from IMC; and a further sample from Avonlea - a coarse-grained product that it was felt might be more easily dispersed. Three levels of addition were examined: 0.5, 0.8 and 1.2% based on dry weight of shale. These levels were expected to cover the degree of improvement desirable for current production. On conclusion of the studies at the 0.5% level, it was elected to concentrate the work on the Burlington shale, as it is the most used and the least plastic of the two, and hence the most troublesome.

The Volclay, a sodium bentonite, showing the expected gel-type structure, was thoroughly dispersed in less than 4 h, and showed no appreciable settling: at the highest concentration it was still pourable with agitation and obviously pumpable. The Dixie Bond (coarse-ground calcium bentonite) dispersed readily but began to settle rapidly when unstirred. The Avonlea bentonite also dispersed readily. Although it developed a pourable gel structure, some settling of coarse particles was observed at all concentrations: the settled particles appeared to be both mineral and organic and presumably comprised impurities that would normally be ground up in the usual fine grinding process or rejected in the classification and recovery system. Figure 4 compares the plastograms for the 3 additives to both shales at the 0.5% level. All three raise the Burlington peak height above the 900 m.g level, but this level of addition has little effect on the peak height of the Streetsville shale. The differences in effect probably do not exceed the normal Plastograph reproducibility. Two other effects are notable. The curves are smoothly rounded, indicating that the addition of plastic clay mineral has

counterbalanced the inherent dilatent tendencies of the shale, although a remnant is clearly discernable in the curves for Dixie Bond. Also the curves are displaced to the left, indicating that equal plasticity is developed at water contents lower by on the order of 1%.

The curves for the 0.8% additions to Burlington shale show no significant differences (Fig. 5) and only minor increases in peak height were recorded with additions at the 1.2% level (Fig. 6). It should be recalled that the earlier curves (Fig. 2) showed really substantial change only at the 2 and 4% levels of addition.

At this point, two other considerations arose. First, the effect of pugging time! A 16.5% addition of water, corresponding to the peak maximum of the untreated shale, was added as rapidly as possible (within 2 min) to the dry Burlington shale containing the usual plant additives, the mixing chamber was covered with a glass plate to inhibit evaporation, and the instrument was allowed to run until the consistency levelled off (Fig. 7). The procedure was repeated, with the addition of dry coarse Avonlea bentonite at the 0.8% level: the total water addition was 16.0%, corresponding to the peak maximum for this mixture. A third run was conducted, duplicating the second except that all the additives were first mixed in the water and slurried for ½ h. The shale with no bentonite reached its maximum peak level only after 22 min. With the dry addition of bentonite, the maximum was reached in 18 min but the early rate of rise in consistency is appreciably faster in keeping with the previously noted behaviour where the bentonite-bearing mixtures reached equal consistency at lower water contents. When the bentonite was added wet a further improvement in rate of plasticity development can be seen, with the maximum level being attained in only 12 min. This confirms the prevailing opinion that slurried additions are more effective than dry ones, doubtless owing to better dispersion throughout the mass. It is also of some interest to note the effect of a further addition of water to the fully pugged materials, shown by the broken lines. A quick addition of another 2% of water when the curve has essentially levelled off is reflected first in an apparent drop in consistency. This is an instrumental effect only; the water flows into the channels behind the rotating knives, overlubricating their tracks. However, as the moisture is mixed-in the curve quickly rebounds to a significantly higher level than that previously determined to be inherent in the material. It seems most likely that the additional

soaking of the surfaces of the shale particles serves to loosen plastic clay particles from these surfaces, a sort of weathering effect, resulting in increased consistency. This would appear to bear out what every experienced pugmill operator seems to known instinctively: when the power to the extruder begins to rise, a quick shot with the hose directly into the sealing augers at the front of the mill will quickly remedy the situation and allow time to adjust the rate of water addition at the back of the mill.

This phenomenon does have some bearing on a second question, i.e., what if any is the consequence of the laboratory procedure of oven-drying the shale prior to plastography? Normal bank moisture is on the order of 3.5 to 4.5%, and this moisture is presumed to be removed by drying at 105°C for 24 h. A sample was re-dried at 105°C and found to have picked up about 0.5% of water from the laboratory atmosphere. The same sample again re-dried at 200°C showed an apparent further loss of 0.08%. It was however impossible to precisely determine the weight of the dried shale as it is exceedingly hygroscopic - even in the dessicated chamber of the precision balance it could be seen to be gaining weight at a rate too great to allow for any degree of precision. As Ottawa is highly humid at all times, and particularly and variably so during the summer months, it seems likely that all of the curves are subject to some correction factor of about 0.5%. This may explain some minor anomalies in the relative positions of similar curves obtained at different times.

An aliquot of "dry" shale (i.e., 0.5% water) was equilibrated in a sealed container over water, reaching a reasonably constant 4.2% absorbed water in 6 days. The plastogram for this material, adjusted for the initial moisture content is compared in Fig. 8 with that of the original dried material: the curves are closely similar. In fact, were the "dry" curve adjusted for the original 0.5% moisture content of the shale, the rising portions of the curves would be nearly identical. That the peak for the dry material is wider than that for the wet shale is attributed to the continual absorption of some water into the dry shale particles, not occurring in the pre-wetted material that therefore became over-wet sooner.

To further confirm the effect of drying, a sample of green brick from the then-current production and of the shale from which it was manufactured (designated "Burlington II") were examined. These materials were kept tightly enclosed in polyethylene to prevent moisture loss. The moisture

content of the shale (bank moisture) was determined to be 6.7% of dry weight; that of the green brick was 13.1%. Both samples were examined on the as-received basis: the sample size was the usual 200 g dry weight, adjusted for moisture content. (A portion of the green brick was gently crumbled in the fingers to a particle size appropriate to plastography, to preclude production of further fines.) Aliquots of both materials were dried at 105°C for 24 h, and again examined. In addition, a sample of shale was run with additions of 1.0% Avonlea (coarse) bentonite, 0.04% lignosol, and 0.125% $BaCO_3$: as customary, the additives were slurried in the first 10% water addition, for 4 h prior to plastography.

The curves are shown in Fig. 9. The dry Burlington II shale is less plastic than the original sample, both in peak height (740 m.g vs 800 m.g) and width. It also requires less water to achieve maximum consistency. It may be presumed that the Burlington II sample originates from greater depth in the shale pit, where the material is harder and less amenable to processing: the production of fewer plastic fines during grinding of the harder shale would reflect in lower plasticity and lower water requirement owing to less surface area to be wetted. The plastogram for the dried brick material, on the other hand, reaches a peak of 800 m.g, equal to that of the original Burlington shale sample. The conclusion, then, is that shear under high pressure in the auger barrel effectively abrades the coarse shale particles, producing an increased proportion of plastic fines.

The curves for the as-received Burlington II shale and brick materials are also shown in Fig. 9, adjusted for original moisture content. There is no significant difference in peak heights owing to drying at 105°C, given that reproducibility of the plastograms is about 5% of peak height. As with the original Burlington shale sample (Fig. 8), the peaks are narrower owing to less water being absorbed by the pre-wetted particles, which allows the particle surfaces to be over-wetted more quickly.

The addition of bentonite (Avonlea coarse) to the Burlington II shale appears to be more effective than with the original shale, probably because the base consistency is lower (i.e., fewer plastic fines to begin with). An addition of 1.0% bentonite raises the peak from 740 to 900 m.g (about 22%) vs. about 24% for an addition of 1.2% of the same bentonite to the original Burlington sample.

CONCLUSIONS

1) Both the Streetsville and Burlington shales have ample plasticity for extrusion of mechanically sound brick. The harder Burlington shale is less tractable than the softer strata owing to production of fewer fines during grinding.

2) All of the bentonites examined are capable of being well-dispersed in 4 h with high-shear mixing. The calcium bentonite and coarse-ground sodium bentonites are more readily dispersed than fine-ground sodium bentonites.

3) Additions of from 0.5 to 1.2% bentonite increase plasticity and should be useful during difficult periods as when the deeper, harder shale strata are being processed. Greater additions would be expected to allow successful production of more complex shapes.

4) Sodium bentonites, owing to their thixotropic nature, tend to counter-balance the inherent dilatency of the ground shales and their use should result in more uniform brick properties, owing to reduced internal stresses arising from irregular flow in the augers and dies. Calcium bentonite, although about equally effective in raising consistency levels, appears to exacerbate the dilatent tendencies.

5) Bentonite additions promote development of equal plasticity at lower water content and reduced pugging times.

6) Drying of the shale at temperatures on the order of the boiling point of water does not significantly affect their inherent plasticity.

ACKNOWLEDGEMENTS

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2. Bell, K.E. "Evaluation of three Saskatchewan bentonites as plasticizers for brick shales"; Division Report MRP/MSL 82-1 (CR); CANMET, Energy, Mines and Resources Canada; 1982.

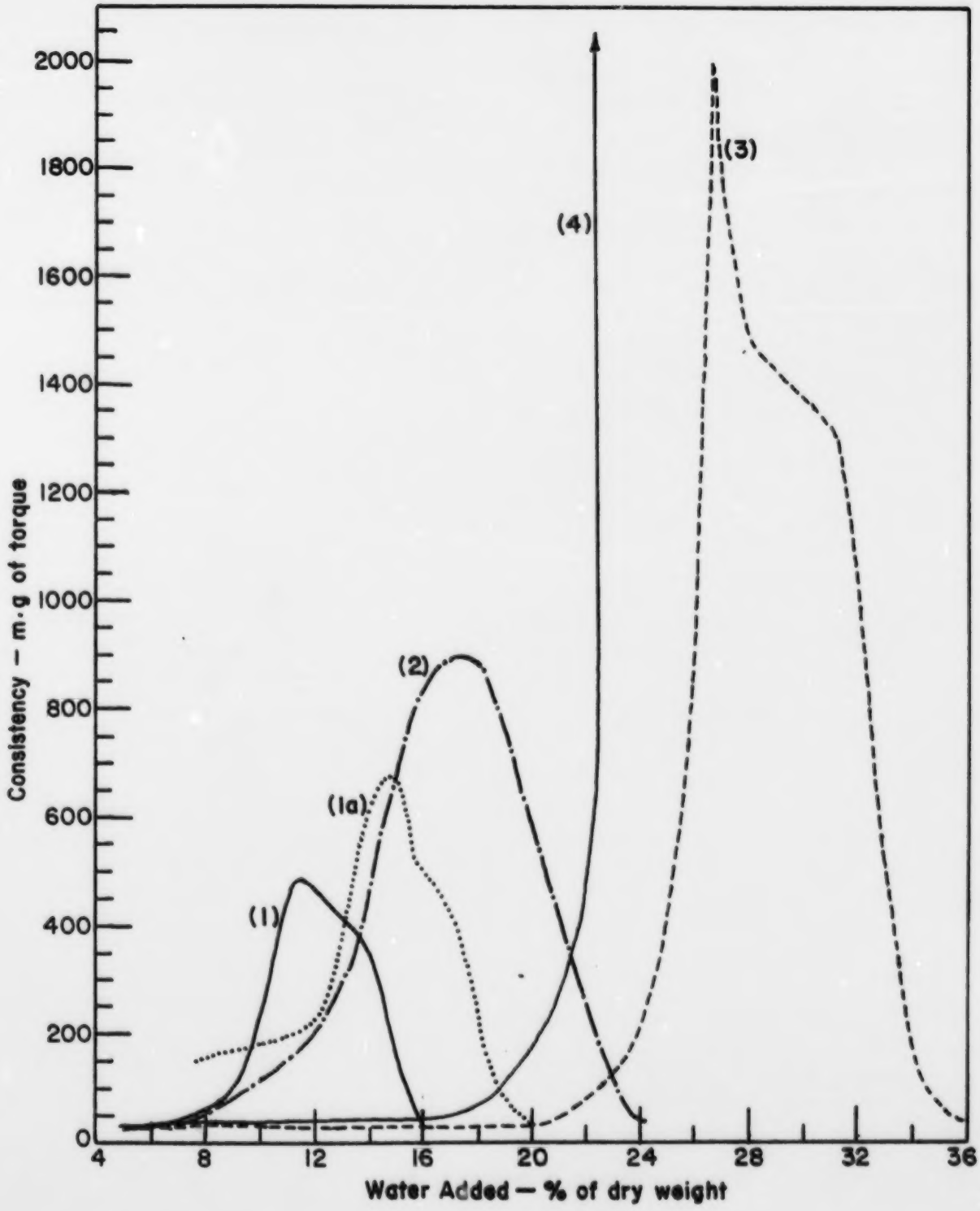

Fig. 1. Plastograms of some typical Canadian materials.

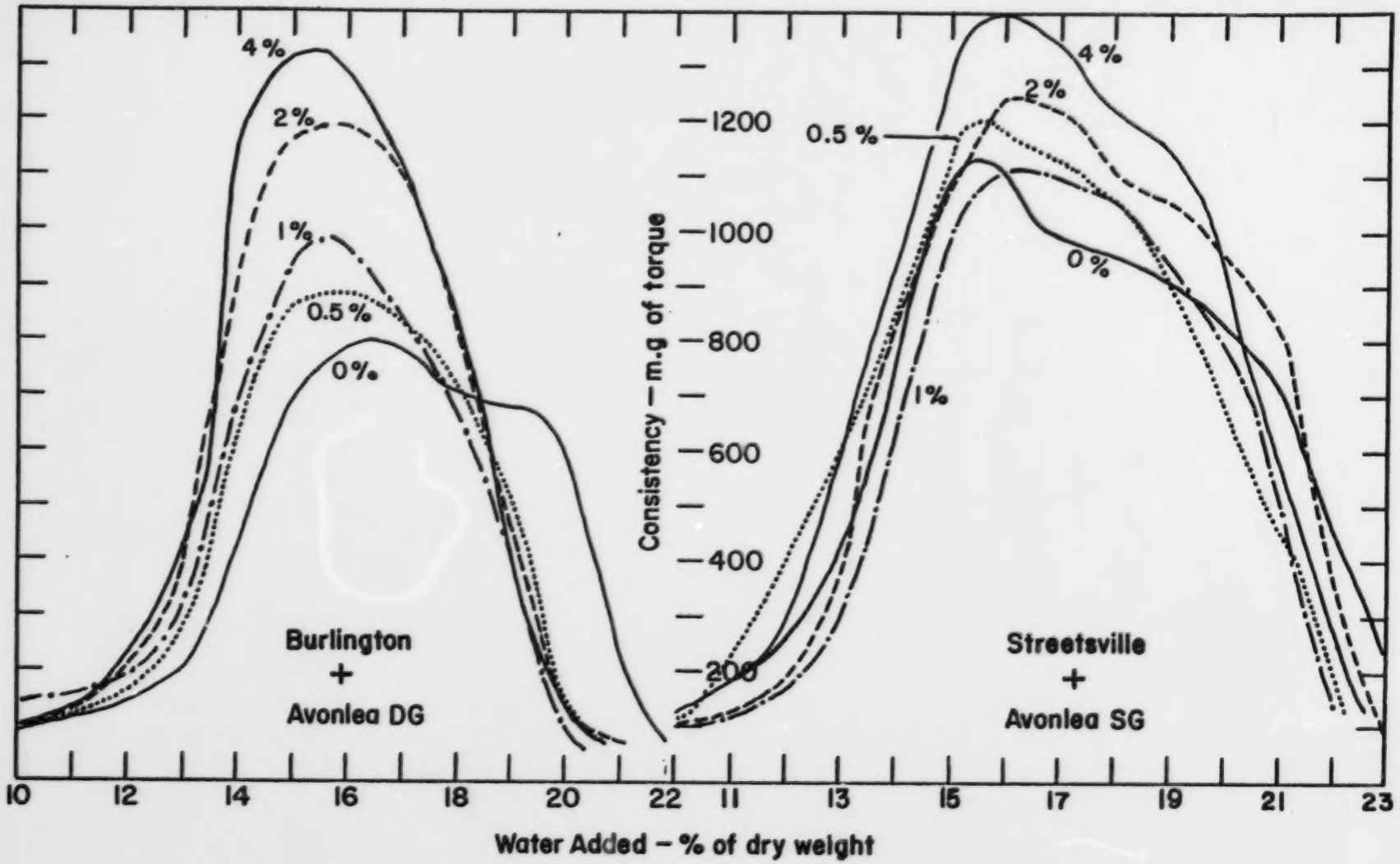

Fig. 2. Effect of additions of Saskatchewan bentonites on the plasticity of Canada Brick shales.

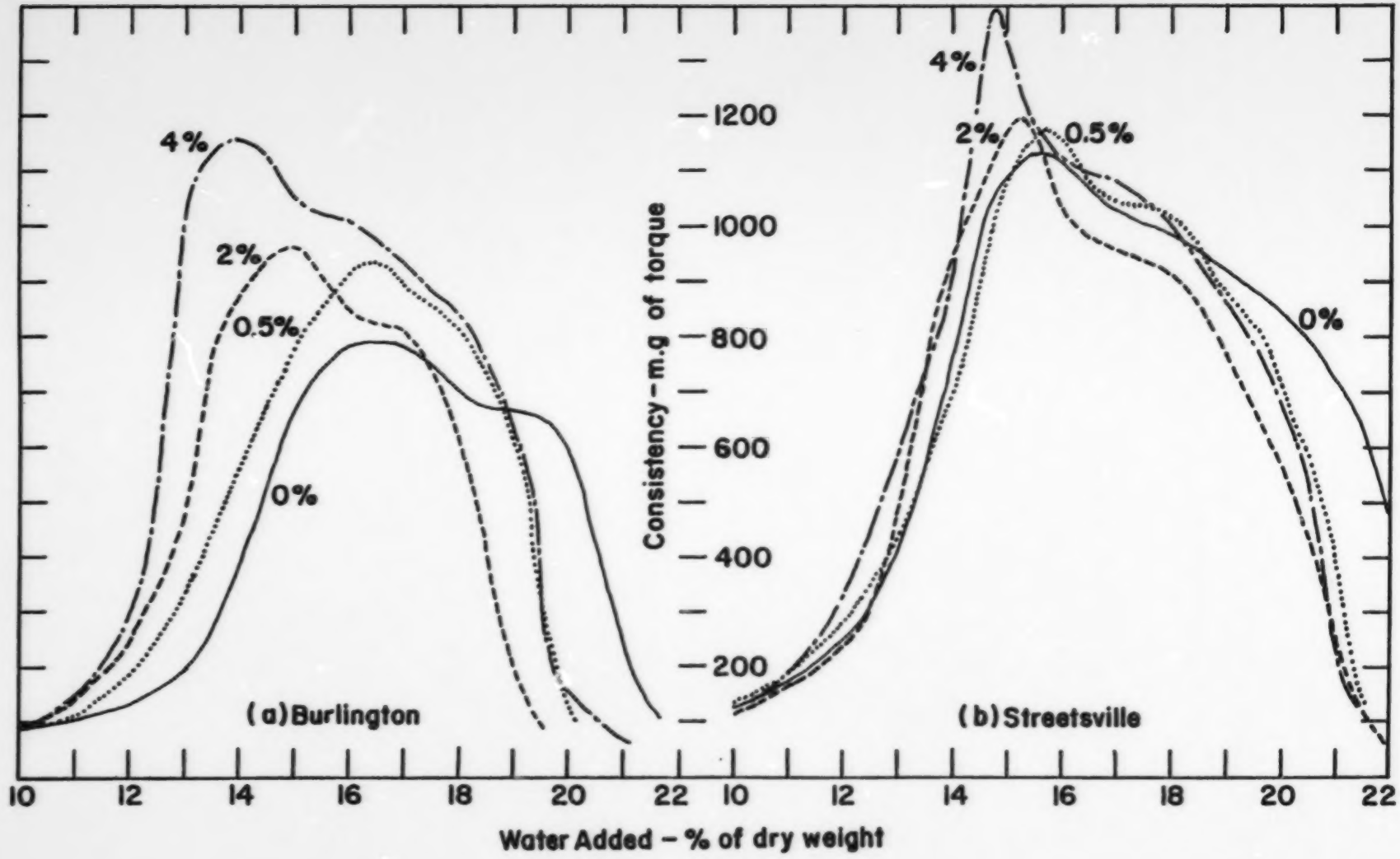

Fig. 3. Effect of calcium bentonite additions on the plasticity of Burlington and Streetsville shales.

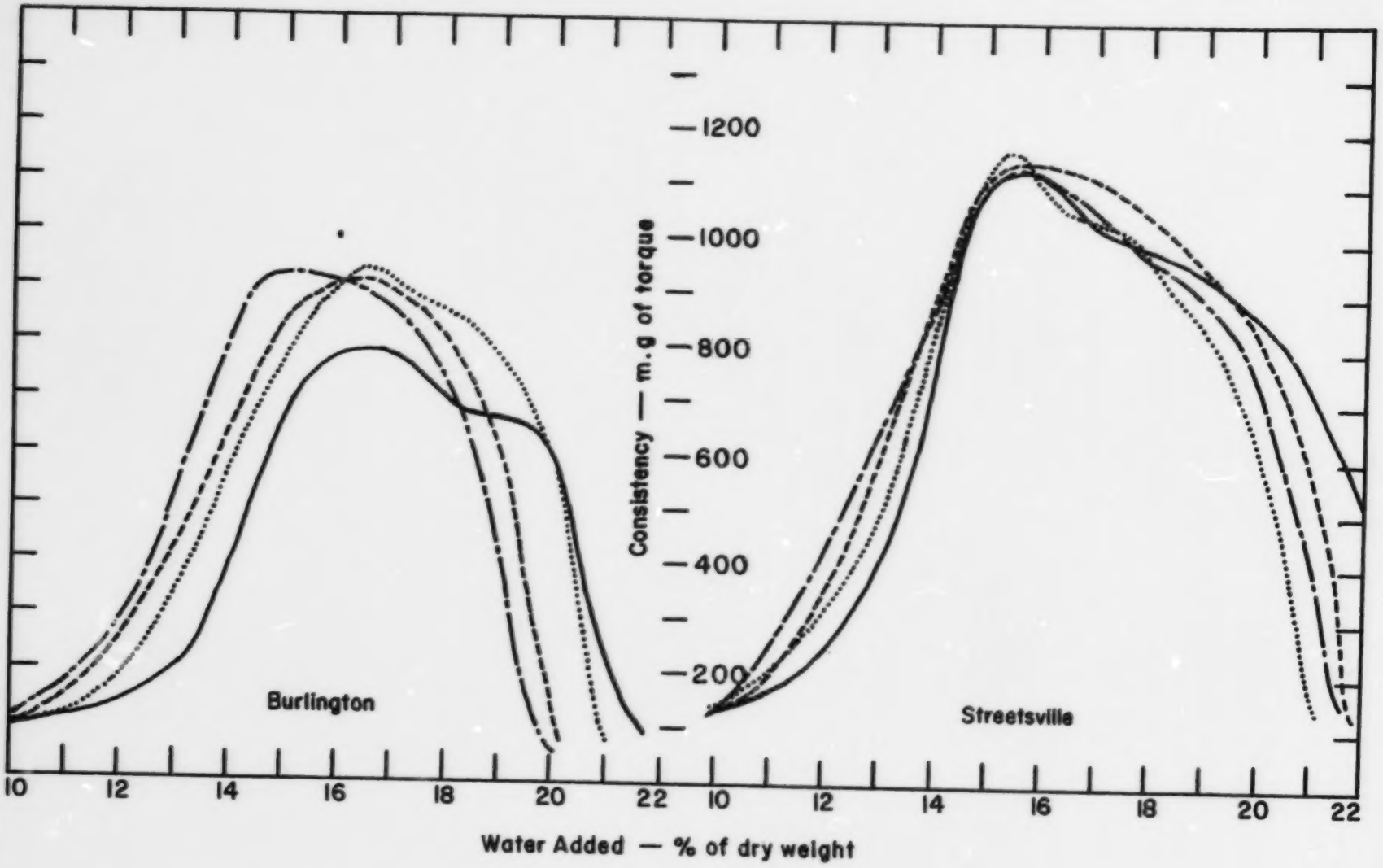

Fig. 4 – Effect of 0.5% bentonite additions to Canada Brick Company's shales: Shale ————; Dixie Bond ·····; Volclay --------; Avonlea (coarse) —·—·—.

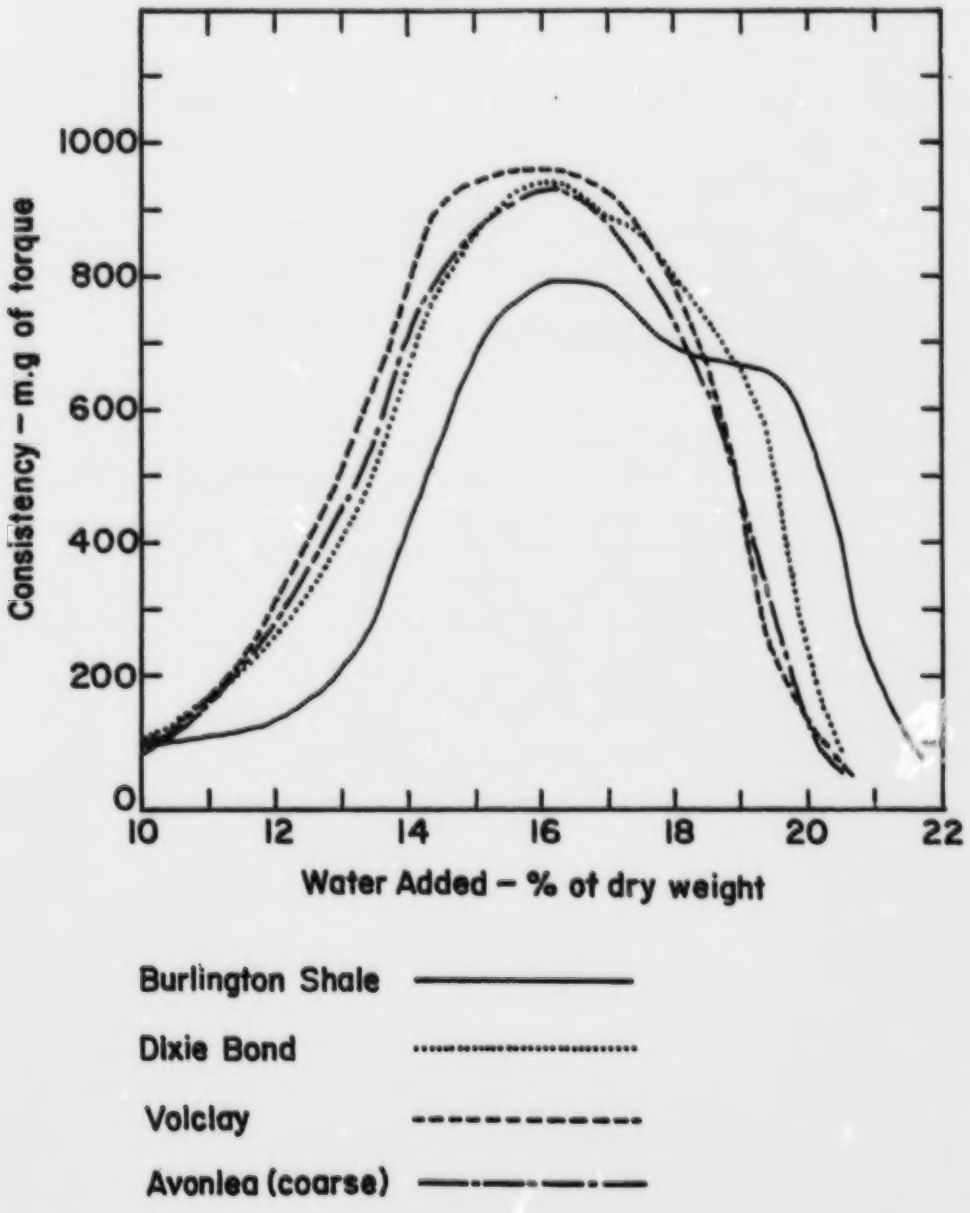

Fig. 5. Effect of 0.8 % bentonite additions to Burlington shale.

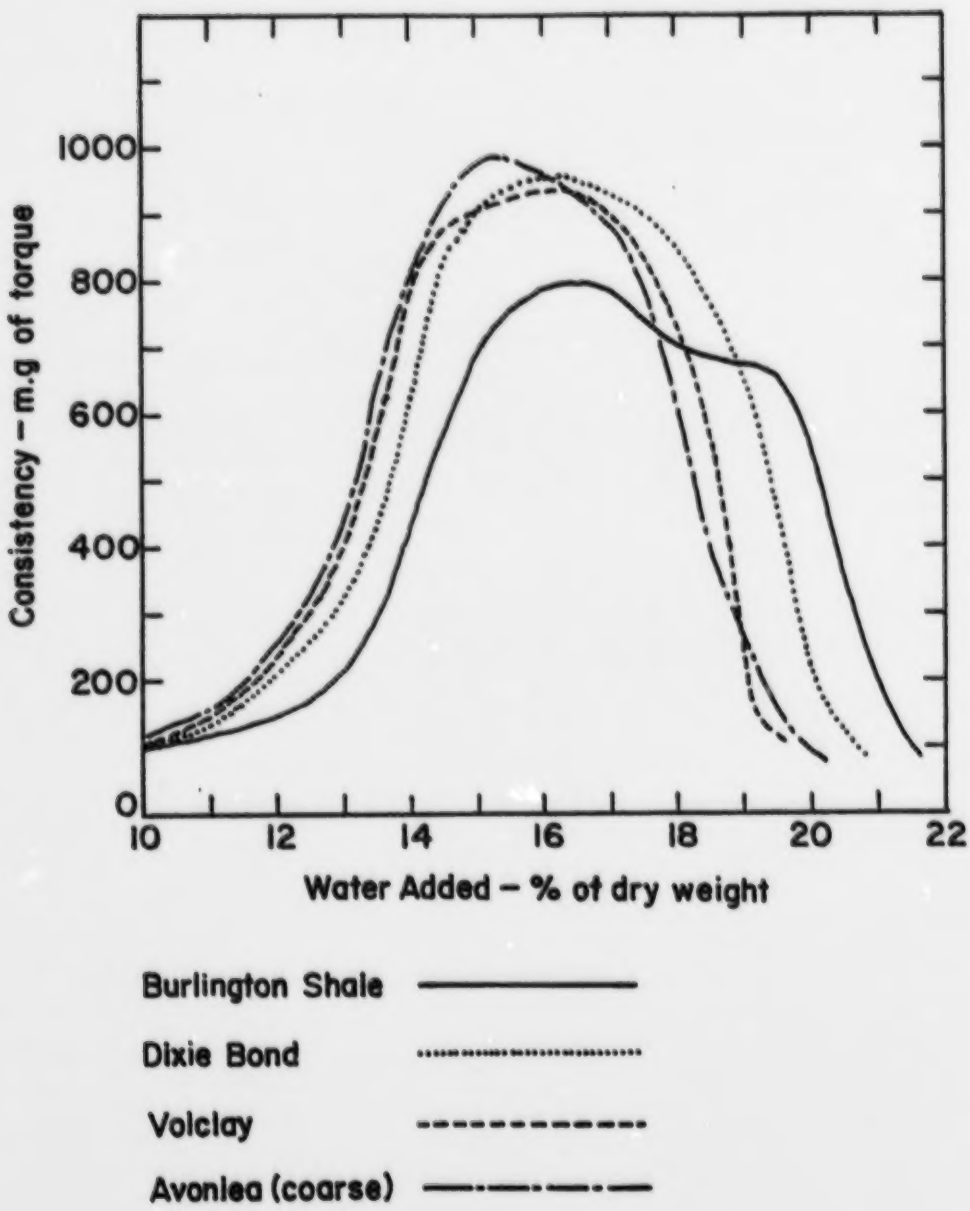

Fig. 6. Effect of 1.2 % bentonite additions to Burlington shale.

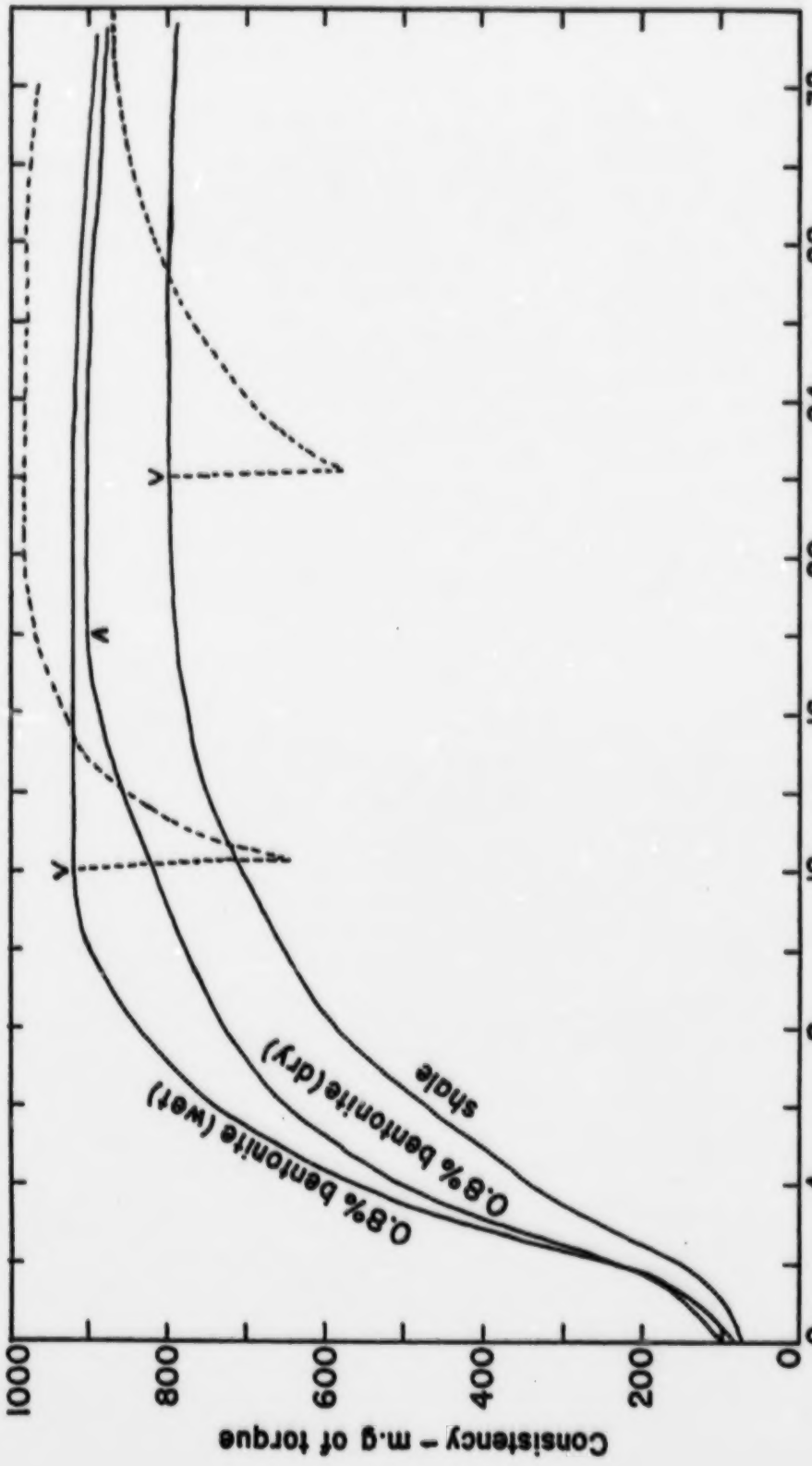

Fig. 7. Pugging behaviour of Burlington shale/Avonlea (coarse) bentonite mixtures.

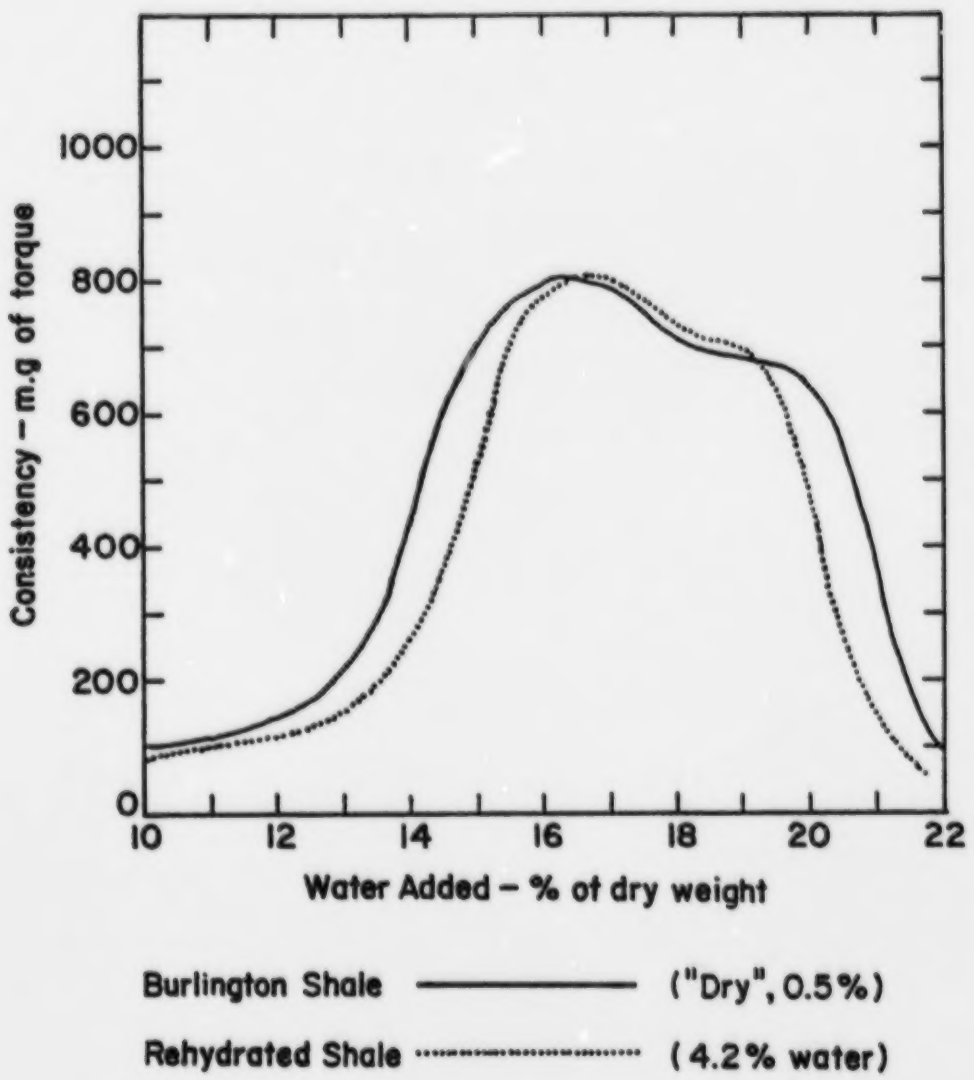

Fig. 8 - Effect of original moisture content on observed plasticity.

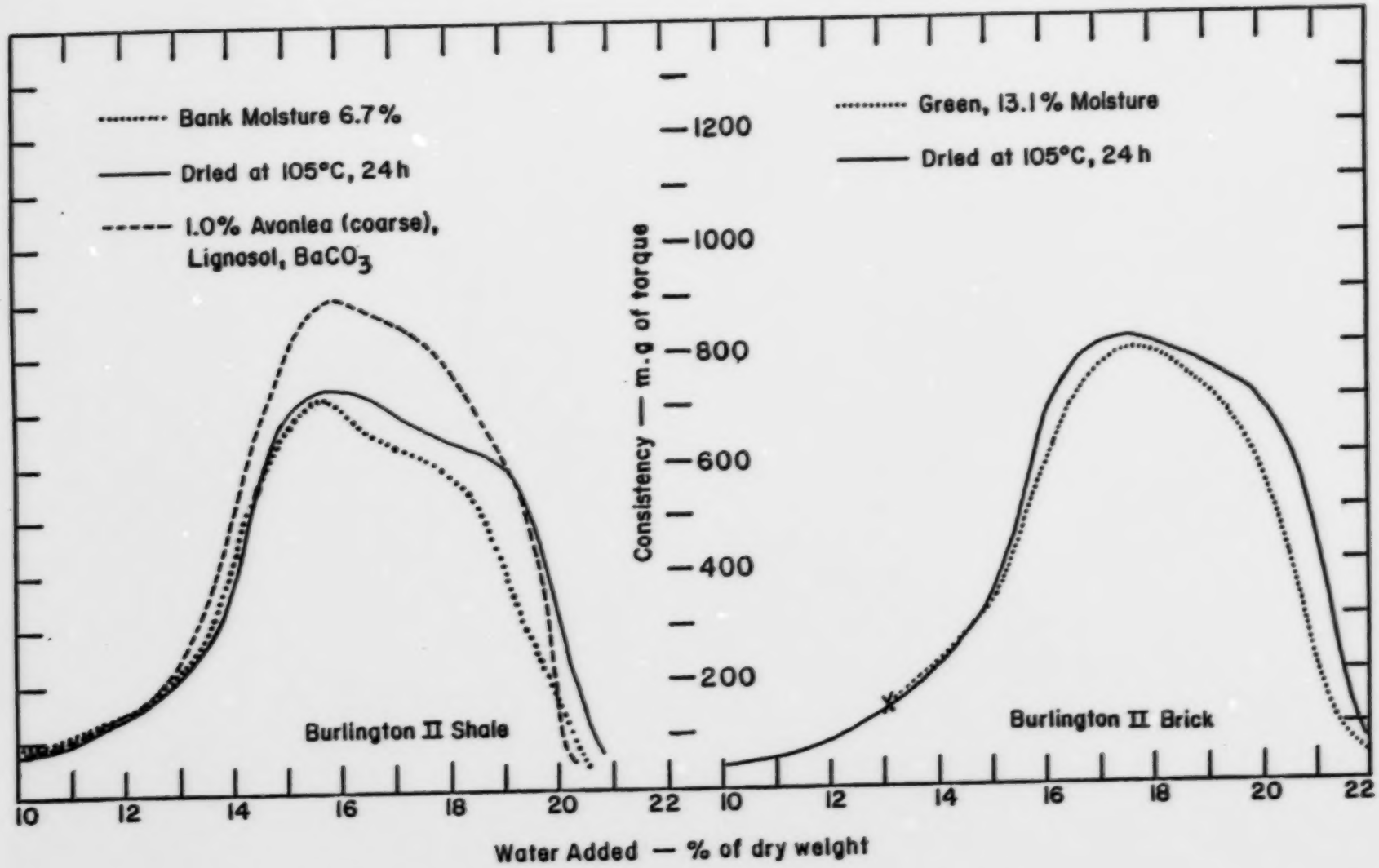

Fig. 9 – Influence of original moisture content on observed plasticity of Burlington II materials.